ASIAEX East China Sea Experiment and Scattering from the Sea Surface

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LONG-TERM GOALS

To develop physics-based, predictive sonar models for mid- to high-frequency scattering and propagation phenomena that are influenced by the air-sea interface. The models are governed by wind speed, and parameterizations of the sea surface wave spectrum, near-surface bubble population, and near-surface ocean dynamics.

OBJECTIVES

(1) Analyze and model sea surface scattering measurements, and sea surface environmental measurements, made during the Asian Seas International Acoustics Experiment (ASIAEX) conducted in the East China Sea (May-June 2001). The acoustic data consist of measurements of   vertical coherence for single and multiple-interaction forward scattering from the sea surface, made simultaneous with measurements of the sea surface directional wave spectrum, and other measurements of the air-sea interface.

(2) Analyze and model measurements of surface reverberation caused by near-surface bubbles, with work directed towards further verification of the model (by the PI) for sea surface reverberation contained in the APL-UW high-frequency ocean environmental acoustic models set.

APPROACH

The approach to modeling spatial coherence is based on identifying the probability density functions (PDF) that describe angular spread at the receiver position for vertical and horizontal arrival angle; these being $P_v(\theta_v)$ for vertical arrival angle, and $P_h(\theta_h)$ for horizontal arrival angle [1]. The PDFs are constructed by summing the scattered intensities associated with discrete vertical and horizontal arrival angles. For a given patch of sea surface, the scattered intensity depends on the sea surface bistatic cross section, computed here with the small slope approximation. The angle PDFs are Fourier transformed to give a model for spatial coherence. An alternative approach was also used that is based on applying the van Cittert-Zernike theorem from radio astronomy [2]. The van Cittert-Zernike theorem relates the spatial correlation across an array to the distribution of incoherent intensity on the radiating surface that the array has sensed (for astronomical geometries this relation is via Fourier transform). We have applied the van Cittert-Zernike to our measurements of spatial coherence by assuming that the ensonified sea surface becomes in effect an incoherently radiating surface, with excellent results. The advantage of this approach is that it can be used to study propagation of spatial

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14. ABSTRACT

To develop physics-based, predictive sonar models for mid- to high-frequency scattering and propagation phenomena that are influenced by the air-sea interface. The models are governed by wind speed, and parameterizations of the sea surface wave spectrum, near-surface bubble population, and near-surface ocean dynamics.

15. SUBJECT TERMS

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coherence and the spatial coherence in paths that have undergone multiple interactions with the sea surface.

The approach to analyzing the high-frequency surface reverberation measurements has, in part, as its basis the controlled laboratory study on scattering from a bubble close to a roughened air-water interface [3].

WORK COMPLETED

ASIAEX East China Sea project coordination: A post-experiment analysis meeting was hosted in January at APL-UW, involving U.S. and PRC scientists who planned and carried out the East China Sea experiment held 6 months earlier, and U.S. scientists participating in data analysis.

Data analysis and reporting: Initial analysis of ASIAEX spatial coherence measurements from the East China Sea was completed, with results presented at the SACLANT Acoustic Variability conference [4]. Analysis of field measurements of high-frequency reverberation caused by near-surface bubbles was completed with results in reported in [5].

RESULTS

Computation of the sea surface bistatic cross section requires an estimate of the two-dimensional sea surface covariance function $C(\zeta,\xi)$. Figure 1 shows how $C(\zeta,\xi)$ is derived from a combination of field measurements of directional sea surface roughness using a wave buoy, plus a model. The covariance function from the buoy data (upper left plot) is supported by surface roughness wavenumbers up to 1.13 rad/m. For higher wavenumbers, a model by Plant [6] is used to generate a spectrum and ultimately a covariance function that is supported by wavenumbers > 1.13 rad/m (upper middle plot). This function is then linearly combined with the buoy covariance function to form a $C(\zeta,\xi)$ used in the acoustic scattering calculations and spatial coherence modeling (upper right plot). The lower left plot shows a cut of this combined covariance function down one axis (dashed line in upper right plot).

Figure 2 shows model curves for the absolute value (upper plots) and real part (lower plots) of vertical coherence plotted against element spacing normalized by wavelength, compared with measured values at 8 kHz and 20 kHz from the East China Sea. The upper plots also show 8 kHz and 20 kHz model predictions for horizontal coherence for the same conditions and geometry. The solid model curves include the influence of the downward refracting profile in the East China Sea as measured by CTD. For comparison, a 20 kHz model curve for vertical coherence is also computed using iso-speed conditions (dashed curve), with resulting degradation (albeit slight) in model-data agreement. A simple interpretation is that the downward refracting conditions tend to compress the set of vertical arrival angles at the receiver (i.e., via Snell's law) and thereby increase vertical coherence.

Figure 3 summarizes the study on high frequency backscattering from near surface bubbles [5]. Estimates of sea surface backscattering strength made at 30 kHz and 20° grazing angle are plotted against wind speed according to whether the wind speed was rising (filled symbol) or falling (open symbol). The different symbol types indicate separate field experiments. The curve labeled BUBBLE SCATTERING is the model discussed in [5]; two model curves bracketing the central one result from computing this model using as input the measured wind speed + 1 m/s (upper curve) and the measured wind speed – 1 m/s (lower curve). The dashed curve labeled BRAGG SCATTERING is from [6] and shown here for comparison only to highlight the dominant role of bubbles as the source of

reverberation in this frequency and grazing angle range.   Another key result is the hysteresis effect that is exhibited in the data, wherein for a given wind speed there is a tendency for the scattering level to be higher if prior winds have been falling.
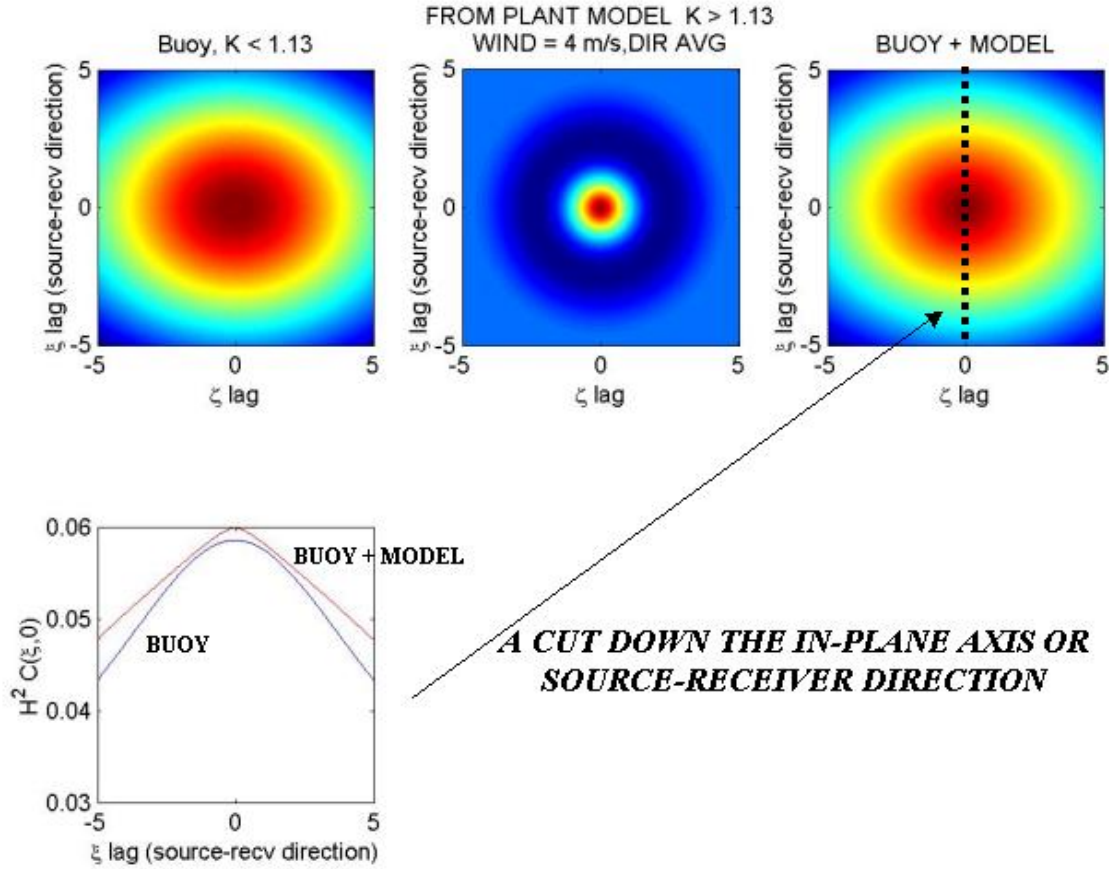

Figure 1. Upper left plot: Estimate of 2-dimensional sea surface roughness covariance function $C(\zeta,\xi)$ made from directional wave buoy in the East China Sea during which wind speed was 4 m/s. This estimate is supported by wavenumbers K < 1.13 rad/m. Upper middle plot: model for $C(\zeta,\xi)$ derived from wave spectral model by Plant [6], for which only wavenumbers K > 1.13 rad/m are used. Upper right plot: linear superposition of the K < 1.13, and K > 1.13 covariance functions. Lower left plot: cut down one axis of the combined covariance function.
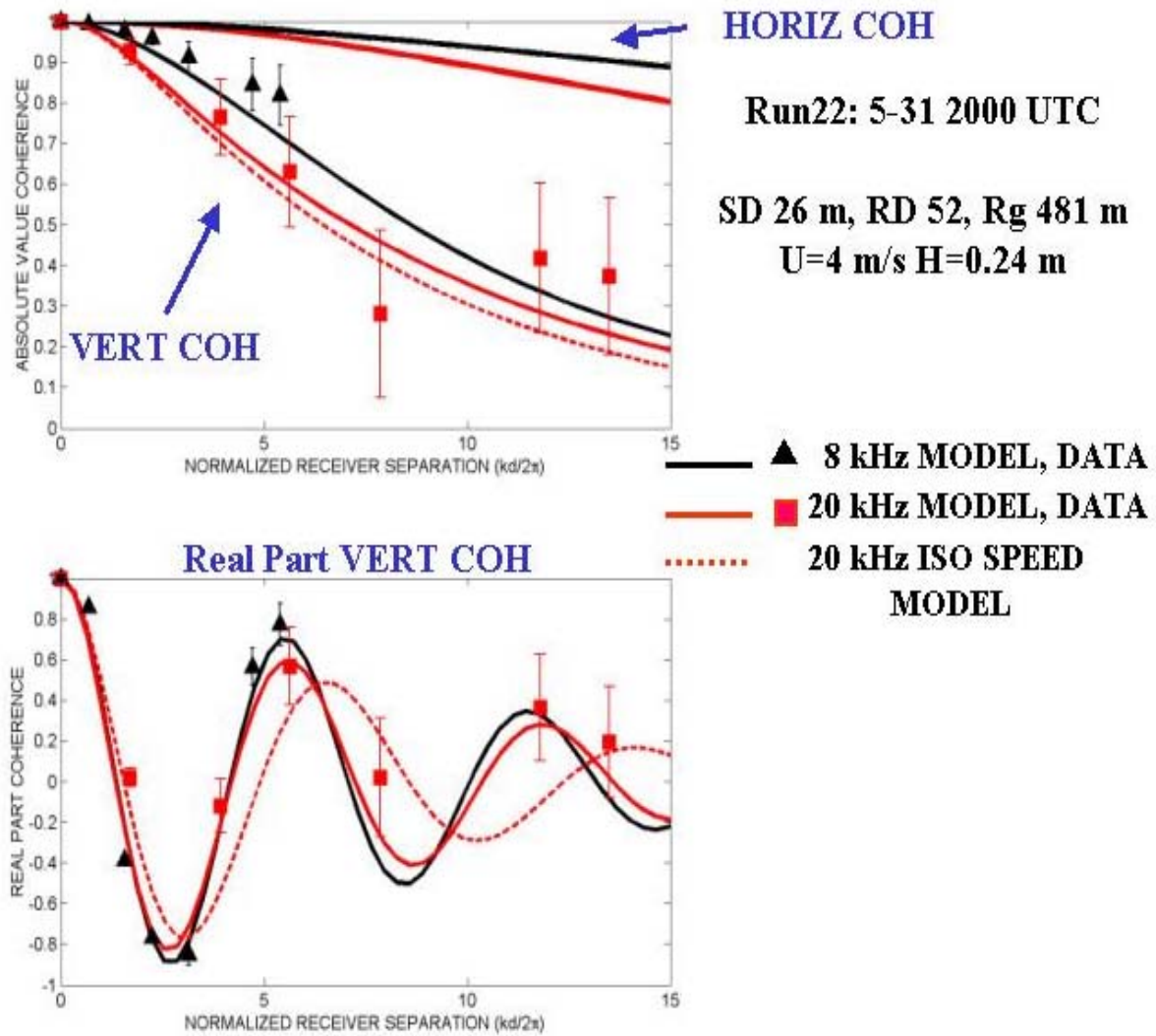
***Figure 2**. Model curves for the absolute value (upper plots) and real part (lower plots) of vertical coherence plotted against element spacing normalized by wavelength, compared with measured values at 8 kHz and 20 kHz. The upper plots also show 8 kHz and 20 kHz model curves for horizontal coherence for the same conditions and geometry. A 20 kHz model curve for vertical coherence is also computed using iso-speed conditions (dashed curve in upper and lower plots).*
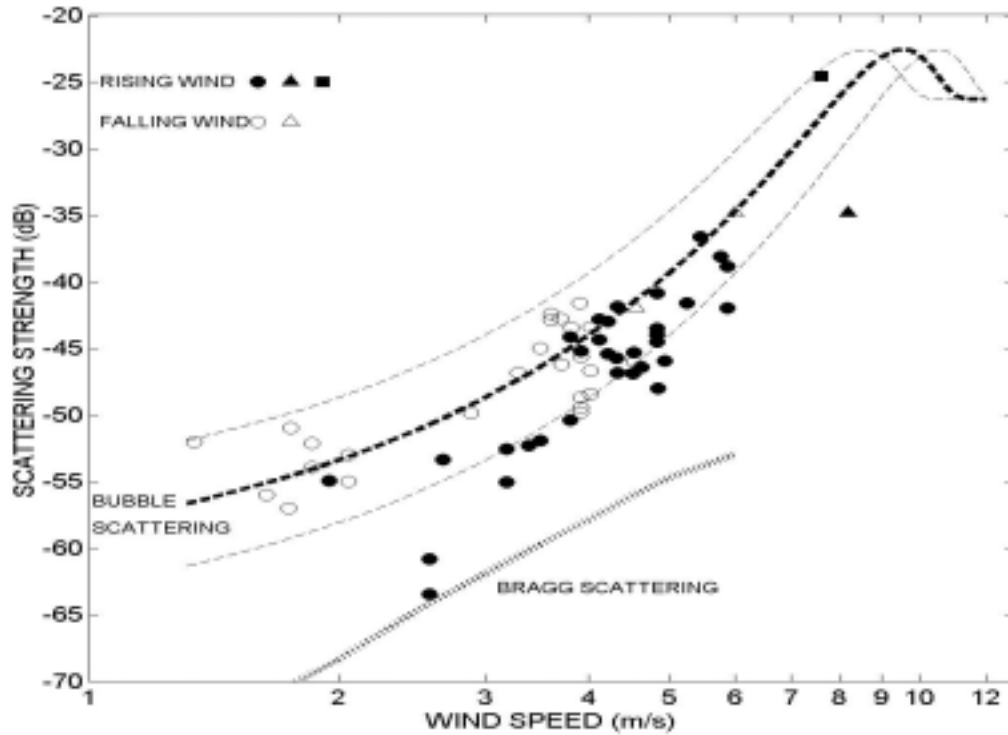
***Figure 3. Estimates of sea surface backscattering strength made at 30 kHz and 20° grazing angle
plotted against wind speed according to whether the wind speed was rising (filled symbol) or falling
(open symbol) on average during the previous hour. The different symbols indicate separate field
experiments although the majority of data are from one experiment. The curve labeled BUBBLE
SCATTERING is the model in [5]; two model curves bracketing the central one result from
computing this model using as input the measured wind speed + 1 m/s (upper curve) and the
measured wind speed – 1 m/s (lower curve). The dashed curve labeled BRAGG SCATTERING is
from [6], and is shown for comparison only and to highlight the dominant role of bubbles.***

IMPACT/APPLICATIONS

With naval operations becoming ever more littoral oriented, the sea surface becomes increasingly
important in setting the performance bounds for naval sonar systems. Our studies in high-frequency
sea surface reverberation provide a physics-based foundation for an operational model (by the PI, and
part of the APL-UW models set), that is utilized by SACLANT, Naval Coastal System Station (CSS),
and other naval sonar research institutions. The uncovering of a hysterisis effect (in the reverberation
wind speed dependence) also points to a source of uncertainty in the present version of this model, and
a means to reduce this uncertainty.

Our studies on forward scattering from the sea surface in the East China Sea have direct application to
models for sonar detection, communication, and imaging, utilizing the sea surface bounce path. At
present, the primary application involves long-range Synthetic Aperture Sonar (SAS), for which our
results on spatial coherence in forward scattering from the sea surface (both data and modeling) are

being used to establish a potential performance envelope, and are being utilized in SAS development work at CSS and Dynamics Technology.

RELATED PROJECTS

Our research is integrated together with several projects (James Miller, D. J. Tang, W. Hodgkiss, Jixun Zhou) within the ASIAEX field program, with focus on propagation, and surface, bottom, and volume scattering effects in the East China Sea.

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P. H. Dahl, "Spatial coherence of signals forward scattered from the sea surface in the East China Sea," (*Invited paper*) *Impact of Littoral Environmental Variability of Acoustic Predictions and Sonar Performance*, N. G. Pace and F. B. Jensen (Eds.), Kluwer Academic Publishers, Dordrecht, 2002.

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